

EFFECT OF DEFECT GEOMETRIES UPON  
BURST CAPACITY OF COMPOSITE  
REPAIRED PIPE

TAY HONG WEI

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG



## **STUDENT'S DECLARATION**

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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(Student's Signature)

Full Name : TAY HONG WEI

ID Number : AA15153

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## ABSTRAK

Pada masa kini, sistem pembaikan komposit telah terbukti berkesan dalam membaik pulih sistem saluran paip. Kaedah ini memberikan beberapa kelebihan seperti ringan, rintangan terhadap keletihan dan rintangan kakisan. Walaupun banyak kelebihan yang ditawarkan oleh sistem pembaikan komposit, beberapa isu mengenai faktor-faktor yang mempengaruhi tingkah laku dan prestasi sistem ini tidak difahami sepenuhnya. Kesan geometri kecacatan paip diperbaiki komposit adalah salah satu faktor yang boleh menjejaskan kapasiti letus paip pembaikan komposit. Walau bagaimanapun, kod reka bentuk yang sedang digunakan hanya mengambilkira kedalaman kecacatan dalam mengira tekanan letus paip pembaikan komposit. Baru-baru ini, terdapat beberapa penyelidikan telah membuktikan bahawa geometri kecacatan (panjang dan lebar) akan mempengaruhi tekanan letus paip, oleh itu terdapat kemungkinan yang tinggi geometri kecacatan juga akan mempengaruhi tekanan letus paip pembaikan komposit. Oleh itu, objektif kajian ini adalah untuk meneroka potensi geometri kecacatan paip diperbaiki komposit ke arah kapasiti letusnya melalui analisis unsur terhingga. Empat model paip diperbaiki komposit telah dibangunkan untuk mengkaji pengaruh geometri kecacatan (panjang dan lebar) ke arah tekanan letus hidrostatik saluran paip diperbaiki komposit. Hasil kajian telah membuktikan bahawa apabila dimensi geometri kecacatan meningkat, tekanan letus paip pembaikan komposit telah menurun. Perbezaan tekanan letus didapati sebanyak kira-kira 20% antara dimensi kecacatan terkecil dan terbesar model paip diperbaiki komposit yang digunakan dalam kajian ini. Sebagai kesimpulan, geometri kecacatan (panjang dan lebar) memberi kesan kepada kapasiti letus paip pembaikan komposit dan penemuan ini boleh digunakan untuk penyelidikan masa depan dalam mengoptimumkan reka bentuk sistem pemulihan saluran paip terutama menyelesaikan masalah konservativiti di dalam kod reka bentuk.

## **ABSTRACT**

Nowadays, composite wrap repair has been proven effective in repairing pipeline system. This method provides several advantages such as lightweight, excellent fatigue and corrosion resistance. Despite many advantages offered by composite repair system, several issues regarding the factors that influencing the behaviour and performance of this system are not fully understood. Effect of defect geometries of composite repaired pipe is one of the factors that may affect the burst capacity of a composite repaired pipe. However, existing design code only considered defect depth in calculating the burst pressure of the composite repaired pipe. Recently, there are some researches proved that the geometries (length and width) will affect the burst pressure of bare pipe, hence there is high possibility that the defect geometries will also affect the burst pressure of composite repaired pipe. Thus, the objective of this study is to explore the potential effect of defect geometries of composite repaired pipe towards its burst capacity through finite element analysis. Four composite repaired pipe models were developed to study the influence of defect geometries (length and width) towards the hydrostatic burst pressure of composite repaired pipeline. The result proved that as the dimension of defect geometries increased, the burst pressure of the composite repaired pipe has decreased. The difference in burst pressure was found to be about 20% between the largest and the smallest defect dimension of composite repaired pipe model used in this study. As a conclusion, the defect geometries (length and width) does affect the burst capacity of composite repaired pipe and the findings can be used for future research in optimizing the design of pipeline rehabilitation system especially solve the problem of conservativeness in existing design codes.

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## LIST OF SYMBOLS

$D$	Pipe diameter
$d$	Depth of corrosion
$t$	Nominal pipe wall thickness
$L$	Measured length of corrosion defect
$d/t$	Ratio of corrosion depth to pipe wall thickness
$(d/t)_{meas}$	Measured relative corrosion depth
$(d/t)^*$	Actual relative corrosion depth to cover uncertainties related to inspection tool
$\gamma_m$	Partial safety factor for prediction model and safety class
$\gamma_d$	Partial safety factor for corrosion depth
$ed$	Factor for defining a fractile value for the corrosion depth
$P_{mao}$	Maximum allowable operating pressure
$StD[d/t]$	Standard deviation for measurement
$SMTS$	Specified minimum tensile strength
$P_s$	Maximum allowable operating pressure (MAOP)
$s$	Specific minimum yield strength (SMYS) of pipe
$P$	Internal design pressure
$E_c$	Tensile modulus of the composite laminate in the circumferential direction
$E_s$	Tensile modulus of the pipe material
$t_{min}$	Minimum repair thickness
$P_{yield}$	Internal pressure of the pipe substrate at yield
$P_{live}$	Pipe internal pressure during repair

## **LIST OF ABBREVIATIONS**

FEA	Finite element analysis
FE	Finite element
FEM	Finite element model
FRP	Fibre-Reinforced Polymer
FRPs	Fibre reinforced polymer composites

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background**

Nowadays, pipelines are one of the safest, most efficient and economical ways to move products such as natural gas, refined petroleum products, crude oil and other fluids from one point to another. It is widely used in the world as the transportation medium of these commodities to promote economic development (Kiefner and Rosenfeld, 2012). The United States has the longest distance of pipelines system in the world, with 1,984,321 km in natural gas transport and 240,711 km in petroleum products. The country with the second longest of pipelines network is Russia with 163,872 km, follow by Canada with 100,000 km (Fan, 2016).

Throughout the service years of pipelines, several factors such as material and construction defects, natural forces, third party damage and corrosion will damage and deteriorate these pipelines. As a result, it will reduce their strength and eventually their service life. These factors could also lead to failures such as leaking and explosion which involve considerable cost and inconvenience to the industry and to the public, if we do not handle this problem very well (Cosham and Hopkins, 2004; Teixeira et al., 2008). This is a serious problem faced by oil and gas industry due to the deterioration of steel pipelines commonly used by oil and gas industry.

On September 6, 2010, San Bruno, a blast has caused a 22-meter-long crater, eight people died and more than fifty were injured. Investigation found that the blast was caused by the natural gas spewing out from a ruptured pipeline. At the same year, 840,000 gallons of crude oil spilled from a ruptured pipeline and spilled into the Kalamazoo River, this was the most expensive accident of pipeline spill in U.S. history, estimated to cost

around \$800 million to cleaning up the oil. According to the research, the 2.5 million miles of America's pipelines suffer hundreds of leaks and ruptures every year, costing lives and money. One of the biggest problem contributing to leaks and ruptures is pipelines are getting older. More than half of the nation's pipelines are at least 50 years old in America (Groeger, 2012). In 2011, in Allentown Pa., a natural gas pipeline made of cast iron and had been installed in 1928 exploded underneath a city street, killing five people who lived in the houses above and igniting a fire that damaged 50 buildings (Groeger, 2012). Most of these pipelines are in need for rehabilitation in order to re-establish their desired operating capacity. Therefore, corrosion and metal loss cause pipeline failures and their repair techniques are of interest to researchers all around the world.

Right now, a lot of rehabilitation techniques and repair methods are available for onshore and offshore pipelines however it is seen that the composite material repair system is increasingly used as the repair methods for pipelines system. The composite material repair system mainly includes three parts which is a high strength Fibre-Reinforced Polymer (FRP) composite wrap, a high-performance adhesive and a high compressive infill material. Composite material repair system provides several advantages such as lightweight, high strength and stiffness, excellent fatigue and good corrosion resistance. Despite many advantages offered by composite repair system, several issues regarding the factors that influencing the behaviour and performance of this system are still not fully understood. These issues include the delamination and debonding between steel pipe and composite, complexity of surface preparation, load transfer mechanisms, performance and contribution of the infill material, conservativeness in existing design codes and effect of defect geometries (Lim et al., 2016). Therefore, further investigation is needed for better understanding on the behaviour of composite repaired steel pipeline to optimize the design of pipeline rehabilitation in regards to the usage of composite repair system.

## **1.2 Problem Statement**

Effect of defect geometries which include depth, width and length of defect upon burst capacity of composite repaired pipe is one of the factors that may affect the burst capacity of a composite repaired pipe. However, existing design codes such as ISO/TS



24817 and ASME PCC-2 only account minimum remaining wall thickness of defective pipe (which is original wall thickness minus defect depth) to design the minimum repair thickness (Lim et al., 2016). Besides that, some existing assessment codes account defect depth and length in determining the remaining strength of corroded pipe, such as DNV-RP-F101. In addition, there are some researches proved that the geometry defect will affect the burst pressure of defective pipe. In 2013, an FEA parametric study done by Dewanbabee and his team found that not only the depth, but the shape of defect geometries will affect the collapse pressure of a pipe (Dewanbabee et al., 2013). Furthermore, in 2004, Cosham and Hopkins found that longitudinal length of corrosion is much more important than the circumferential length of corrosion in controlling the burst strength of a pipe under internal pressure and when axial or bending loads are introduced, the circumferential length must also be considered to determine the burst pressure (Cosham and Hopkins, 2004). Therefore, it is expected that the defect geometries of length and width for composite repaired pipe will affect its burst capacity.

Thus, the purpose of this study is to explore the potential effect of defect geometries (length and width) of composite repaired pipe towards its burst capacity. It is expected that the defect geometries will affect the performance of burst capacity of composite repaired pipe where it may help to improve the accuracy for repair the defective pipe by composite wrap repair system.

### **1.3 Objective**

The aim of this study is to investigate the effect of defect geometries namely defect length and defect width towards burst capacity of composite repaired pipeline. In order to achieve the aim, the objectives of this study are outlined as follows:

1. To determine the burst capacity of composite repaired pipe subjected to various defect geometries (length and width) through finite element analysis (FEA).
2. To evaluate the potential effect of defect geometries (length and width) of composite repaired pipe towards its burst capacity.

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